Trends in Growth Intercept Estimates of Fdc Site Index in Post-Harvest Regenerated Stands on Southern Vancouver Island

Phase III: Analysis of Random Sample Data

Prepared for

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Project: MFS-403-028

31 March 1999

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106-06514/

Executive Summary

This report describes Phase III of the Site Productivity Working Group (SPWG) project to examine potential bias in site index estimates using growth intercept models when applied in post-harvest regenerated (PHR) stands of coastal Douglas-fir (Fdc). Height growth was measured in 25 randomly located sample plot clusters in Tree Farm Licence 46 on southern Vancouver Island. Each cluster contained three 100-m^2 plots where height growth was measured from zero to 15 years breast height age for the four largest diameter trees. Site index was estimated for each height-age measurement and compared to the estimate derived from the 1998 heights and ages.

The major results of the study are:

(1) Site index was under-estimated by 2.4 m on average in the 25 sample plots. The model was unbiased for sample plots below 375 m in elevation and with site indices less than 32.5 m, and biased for plots above 375 m and with site index greater than 42.5 m. This bias may be the result of applying the model outside the range of the data used to fit the model.

(2) Bias decreased from approximately 3.5-m at breast height age four to approximately 2-m at breast height age nine, and remained constant thereafter to at least breast height age 16.

(3) Survivor syndrome had little impact on site index estimates. Top height trees at first measurement remained top height trees 70% of the time.

Acknowledgements

This report was completed with the support of the Ministry of Forests (MOF) Forest Practices Branch and TimberWest Forest Ltd. We thank Pat Martin, *RPF* (MOF Forest Practices Branch), Gordon Nigh, *PhD, RPF* (MOF Research Branch), and Steven Northway, *MF, RPF* (Weyerhaeuser Canada ltd.) for supervising the project. We are grateful to Jim McPhalen, *RPF* (TimberWest Forest Ltd.) for providing access to their inventory database and maps. This project was funded through the Site Productivity Working Group of the MOF.

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1. INTRODUCTION

Growth Intercept (GI) equations estimate site index in young stands using measurements of height and age. Most GI models in BC were developed using height-age data collected from stem analysis of sample trees in subjectively located plots in natural stands. These models are used primarily to estimate site index in young, post-harvest regenerated (PHR) stands and natural stands. The inherent assumption in using GI models is that the height-growth of the stand where the model is applied is the same as the stands sampled to develop the model.

Some practitioners and researchers[1] suggest that the height-growth patterns in young PHR stands may be different than in naturally regenerated stands. The problem is that if early height-growth patterns are different in natural and PHR stands, site index estimates from GI models developed in natural stands may give biased estimates when applied in PHR stands. This bias could result in over-estimates of stand growth and yield and could affect the Timber Supply Analysis process. The Ministry of Forests (MOF) Forest Practices Branch initiated this project to examine the potential site index bias using the GI models developed for coastal Douglas-fir (Fdc).[2]

This project consists of three phases: 1) analysis of experimental data to identify potential factors in site index bias (completed);[3] 2) a work plan to guide the Phase III field sampling (completed); [4] and 3) checking site index bias in young Fdc stands using data from randomly located sample plots (this report). The objectives of Phase III were to:

1. *Examine potential bias in Fdc site index estimated using MOF GI equations.*
2. *Evaluate possible impact of the survivor syndrome on site index estimates.*

This report was completed under contract to the MOF, Forest Practices Branch. The MOF contact was Pat Martin, *RPF*. A.Y. Omule, *PhD*, *RPF*, Guillaume Thérien, *PhD*, and Christie Kovacs prepared this report.

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[1] Hoyer, G.E., N.A. Andersen. 1996. Levels-of-Growing-Stock Cooperative Study in Douglas-fir: report No. 13 – The Francis Study: 1963-90. USDA For. Serv. Pacific Nthwt Res. Stn. Res. Paper PNW-RP-488.

[2] Nigh, G.D. 1997. A Growth Intercept Model for coastal Douglas fir. Res. Rep., Ministry of Forests, Research Branch, Victoria, BC.

[3] J.S. Thrower & Associates Ltd. 1999. Trends in Growth Intercept Predictions of Site Index in Managed Coastal Douglas-fir Stands Phase I: Analysis of Experimental Data. Contract Rep. to MOF Forest Practices Branch, Contract No MFS-402-028. *In press.*

[4] J.S. Thrower & Associates Ltd. 1998. Check Time Trends in Growth Intercept Predictions of Site Index in Managed Stands of Coastal Douglas-fir: Field Sampling Work Plan. Contract Rep. to MOF Forest Practices Branch, Contract No MFS-402-028. *In press.*

2. METHODS

2.1 SAMPLE AREA

Twenty-five sample points were randomly located throughout Fdc leading stands in TimberWest Forest Ltd.'s Tree Farm Licence (TFL) 46 (Figure 1). The TFL is 100,636 ha and Fdc-leading stands are about 37,500 ha (40% of the operable forest land base). The sample population was defined as Fdc leading stands not fertilized, total age 21-40 years, and greater than 3.0 ha in size (1,311 polygons on 16,443 ha). Pre-commercially thinned polygons were included in the population.

Figure 1. Location of TFL 46 on southern Vancouver Island.

2.2 FIELD METHODS

The field methods are described in the work plan completed in Phase 2 of this project. However, some modifications were made after two days of sampling, including:

- Tree measurements were taken in the first three suitable plots in a cluster of nine. The number of potential plots in a cluster was increased from five to nine to minimize the chance of an empty cluster.
- Only Fdc trees were considered for top-height trees.
- Tree height at branch whorls was measured using a height pole instead of the Impulse Laser.
- BEC site series was recorded at each sampling point.

2.3 FIELD DATA

Site index and stand data included:

- Total height and breast-height age of the top height tree and the three largest-diameter Fdc trees in each sample plot.
- Height of branch whorls below breast height and for the first 15 years above breast height.
- Radial increments of cores extracted at breast height.

The data were summarized to estimate site index for each sample cluster and for each of the 15 years above breast-height for each tree. Plot cluster site index was calculated as the average of the

predicted site indices from the three sample points. Stand data included site series and species composition by basal area/ha and stems/ha.

2.4 ANALYSIS

Analyses were based on comparing site index residuals by calendar year and tree age. Residuals were computed as the site index estimated at each year above breast height (predicted) minus the estimated true site index based on the 1998 height and age measurements (observed). Time trends residuals were analyzed using statistical and graphical techniques. Only data from ages greater than three years above breast height were used in the analysis. The impact of survivor syndrome[5] was examined by comparing 1998 site index with estimates from top height trees chosen for previous years using past diameters from increment cores and tree height measurements.

3. RESULTS AND DISCUSSION

3.1 SAMPLE PLOTS

Site index in the 25 sample plot clusters ranged from 31 to 45 m and averaged about 39 m (Table 1). Most plots were in the CWHmm1 and CWHvm1 and on mesic sites (Table 2). Twelve of the 25 plots had been pre-commercially thinned.

Table 1. Sample data summaries.

	Plot clusters	Subplots	Mean	Minimum	Maximum	Std. Deviation
Site Index (m)	25	69	39.2	30.6	44.7	3.47
Breast-Height Age (yrs)	25	69	27.6	17.0	56.0	8.13
Height (m)	25	69	24.5	13.7	39.1	5.56

Table 2. Distribution of clusters (25) among the observed site series.

Subzone	Site Series					Total
	01	01s	03	04	05	
CWHmm1	27%		3%		24%	54%
CWHvm1	26%	4%	2%	1%	5%	38%
CWHvm2	4%					4%
CWHxm2					4%	4%
Total	*57%*	*4%*	*5%*	*1%*	*33%*	*100.0%*

[5] Survivor syndrome is the result of choosing different site trees over time. Trees available to sample at any time are only those that have survived. Trees with the largest diameters that may have been chosen as top height trees in earlier years may have died, been damaged, or have been surpassed in diameter growth by other trees. This may result in different estimates of site index over time.

3.2 SITE INDEX RESIDUALS BY CALENDAR YEAR

3.2.1 Overall

Height-growth patterns were different than predicted by the GI model (Appendix II). This led to the model under-estimating site index by 2.4 m on average for the 25 sample clusters. The bias was statistically significantly different from zero overall, but not in 12 (57%) of the years (Figure 2).

Cluster measurements earlier than 1971 and later than 1991 were not assessed because:

- Not all trees were measured in all calendar years. For this analysis, only years with five or more observations were assessed, this included 1971 to 1991.
- Site index under-estimation was correlated with calendar year because the model is constrained to have a bias of zero in 1998; therefore bias steadily decreased towards zero from 1992 to 1998. To remove this time effect, cluster measurements more recent than 1991 were not assessed.

Figure 2. Average Fdc site index residuals (with 95% confidence interval) by calendar year.

These results contrast with Phase 1 of this study where Fdc site index appeared to be over-estimated using the MOF GI equation with experimental data. This may be the result of less precise methods used to estimate age and height in the experiments. Site index estimates in the experimental data were very sensitive to small changes in age. The ages and heights in this report were taken on every top height tree, and ages were estimated from increment cores in the laboratory and thus may be more accurate.

The data were stratified by elevation, site index, cluster density (stems/ha), and age to help detect trends in site index residuals. Only clusters with height measurements in common years were compared. Stratification could not be done for BEC zone and subzone.

3.2.2 Elevation

Clusters were stratified into three elevation classes: Low (0 – 375 m), Medium (376 – 625 m), and High (>626 m). Data were available for 18 common years in all elevation classes from 1974 to

1991. The residual site index in the low elevation class was significantly less (closer to zero) than the medium and high classes (Table 3). This probably reflects the lack of data from higher elevations in the data used to build the GI model. Only four out of 48 plots (8%) used to fit the GI model were above 375 m.

Table 3. Average residual site index (m) by elevation class.

Elevation Class	N	Mean	Minimum	Maximum	Std. Deviation
Low (0 – 375 m)	18	-0.93	-2.46	0.18	0.77
Medium (376 – 625 m)	18	-3.74	-6.34	-2.10	1.22
High (>625 m)	18	-2.90	-6.63	-0.99	1.55

3.2.3 Site Index

Sample clusters were classified using true site index as Low (site index < 32.5 m), Medium-low (32.5 – 37.5 m), Medium-high (37.5 – 42.5 m), and High (42.5 m +). Data were available for 15 common years in all site index classes from 1975 to 1989. The average site index residuals was negligible in the Low class and relatively high in the High site index class (Table 4). There were statistically significant differences between the residual site indices for all classes except the Medium-low and Medium-high classes. Three of 48 plots (6%) used to fit the GI model had site indices greater than 42.5 m; therefore, it is possible that the model poorly reflects height growth patterns in that class.

Table 4. Average residual site index (m) by site index class.

Site Index Class	N	Mean	Minimum	Maximum	Std. Deviation
Low (< 32. 5 m)	15	0.15	-4.70	1.97	2.58
Medium-Low (32.5 – 37.5 m)	15	-2.09	-4.80	0.75	1.28
Medium-High (37.6 – 42.5 m)	15	-1.70	-2.71	0.13	0.90
High (> 42.5 m)	15	-5.06	-9.85	-2.50	2.38

3.2.4 Cluster Density

A cluster density class was assigned based on number of trees/ha: Low (<500 trees/ha), Medium (500 – 1,000 trees/ha), and High (>1,000 trees/ha). Data were available for 19 common years in all plot density classes from 1971 to 1989. Residual site index was significantly lower (closer to zero) in the Low-density class (Table 5). Bias generally appeared independent of plot density.

Table 5. Average residual site index (m) by density class.

Plot Density Class	N	Mean	Minimum	Maximum	Std. Deviation
Low	19	-1.34	-4.98	0.12	1.49
Medium	19	-3.32	-4.68	-2.11	0.68
High	19	-2.94	-4.80	-0.37	1.08

3.2.5 Site Index Residuals by Stand Age

Comparisons showed a gradual increase in predicted site index from age four to nine years breast height age (Figure 3). After age nine, predicted site index remained constant at about 2 m lower than observed at the time of measurement (average age at time of measurement was about 28 years breast height age).

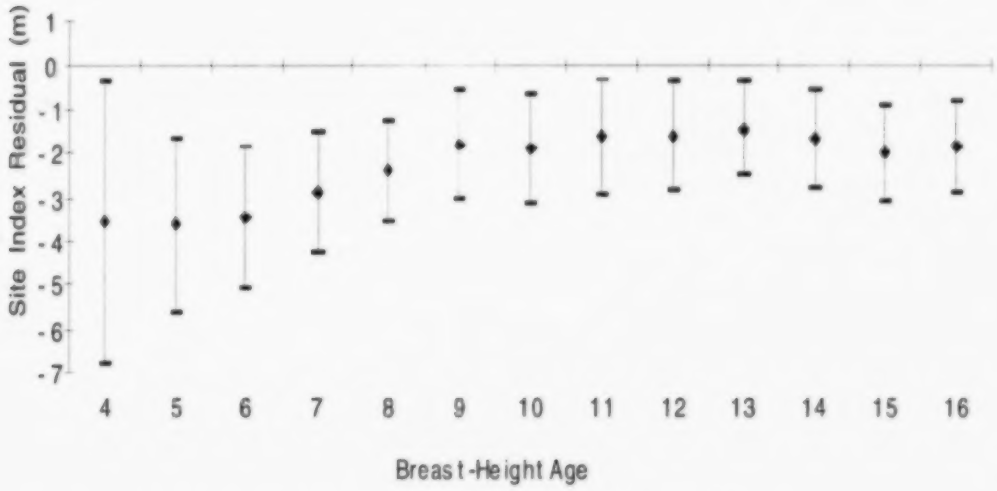

Figure 3. Average site index residuals (with 95% confidence interval) by breast-height age.

3.3 SURVIVOR SYNDROME

Survivor syndrome had little impact on the site index estimates in these sample plots. The top height tree selected in 1998 was also chosen as the top height tree in 70% of the previous measurements (Table 6). This proportion was relatively consistent among calendar years when the number of observations was large (1970-1998). These results support similar conclusions in a study completed in the MOF Schenstrom Plots at the Cowichan Lake Research Station.[6]

Table 6. Frequency of choosing today's top height tree as current top height tree by decade.

Decade	Observed	Frequency of today's top height tree	Probability of choosing today's top height tree
1940-49	12	12	100.0%
1950-59	29	28	96.6%
1960-69	69	38	55.1%
1970-79	304	208	68.4%

[6] Cameron, I.R. 1985. Dynamics of site index curves. Progress report for the MOF, Research Branch.

1980-89	430	299	69.5%
1990-98	186	137	73.7%
Total	*1,030*	*722*	*70.1%*

3.4 ASSUMED TRUE SITE INDEX

In this study, the reference site index was based on the 1998 measurements while the true site index will be achieved when these trees reach age 50. This difference might explain the observed bias. To test this hypothesis, we re-fit the Fdc GI model using the original data with site index defined as height at age 28 years. Comparison of residuals from the 28-year site index was not obviously different from the results based on the 50-year site index.

4. CONCLUSIONS

The results in this study suggest that:

1. Site index of Fdc may be under-estimated using the MOF GI model by 2-3 m in stands with elevation greater than 375 m and on sites greater than about 42 m site index. This potential bias may not be of major concern as most Fdc leading stands are at lower elevations and on lower sites.
2. The potential bias could be the result of applying the GI model outside the range of the data used to fit the model. The Fdc GI model was based mostly on plots below 375 m and plots with site index less than 42.5 m. The data collected for this project showed bias on plots above 375 m and those with site indices greater than 42.5 m. The model appeared unbiased on plots located below 375 m or when site index is less than 32.5 m.
3. Site index bias changed over time. There was a gradual increase in predicted site index from breast height age three to nine, which stabilized from breast height age nine to 16.
4. The survivor syndrome has little impact on potential bias in site index estimates. Top height trees at first measurement remained top height trees 70% of the time.

5. RECOMMENDATIONS

For the second year of the contract, we suggest extending the range of this study to other areas. This will help confirm the magnitude, direction, and sources of bias observed in TFL 46. Possible locations for additional sampling are Canadian Forest Products' TFL 37 on northern Vancouver Island or International Forest Products' TFL 38 north of Squamish.

6. APPENDIX I – LIST OF SAMPLE POLYGONS

Table 7. List of sampled clusters.

Cluster No.	Map	Polygon No.
2	93C060	462
3a	93C079	381
3b	93C079	381
5	92C088	1345
7	92C079	281
9a	92C079	383
9b	92C079	1048
10a	92C079	47
10b	92C078	856
12	92C078	537
13	92C068	1235
14	92C058	2050
15	92C078	589
16	92C088	871
17	92C060	344
20	92C069	2050
23b	92C059	23
26	92C088	494
28	92C088	1337
29	92C078	969
30	92C060	252
35	92C079	619
36	92C079	454
39	92C068	1513
41	92C078	1022

Table 8. List of rejected clusters.

Cluster No.	Map	Polygon No.	Reason for Rejection
1	92C078	340	No access - Snow
4	92C078	713	Fertilized
6	92C077	473	Fertilized
8	93C089	645	Fdc not Leading
11	92C088	1277	Stand too young
18	92C087	3	No access - Snow
19	92C078	718	No access - Snow
21	92C077	535	Fertilized
22	92C078	683	No access - Map not available
24	92C088	733	No access - Gate key required
25	92C078	683	Fertilized
27	92C088	733	Fertilized
31	92C078	543	Fertilized
32	92C077	754	Fertilized
33	92C059	118	Damaged site trees
34	92C078	300	No access - Snow
37	92C079	47	No access - Snow
38	92C078	197	No access - Snow
40	92C088	1523	Replaced by plot 41 by mistake

7. APPENDIX II – HEIGHT-AGE CURVES OF CURRENT TOP HEIGHT TREES

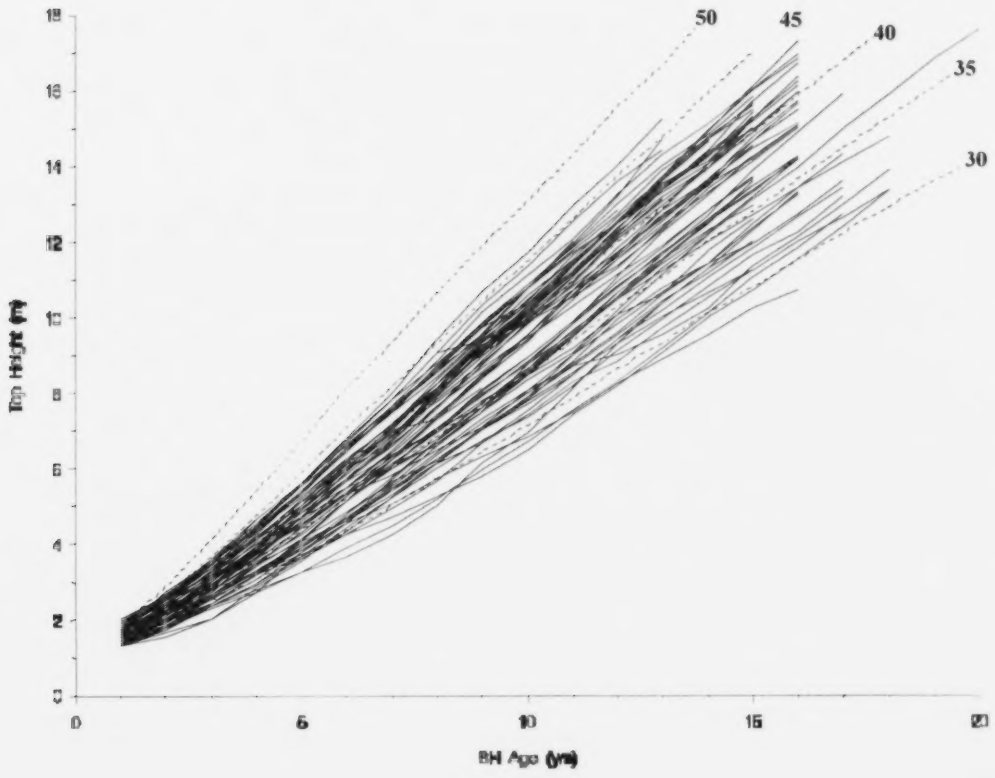

Figure 4. Height-age curves of current top height trees (solid lines) and top height growth implied by GI model (dashed lines).

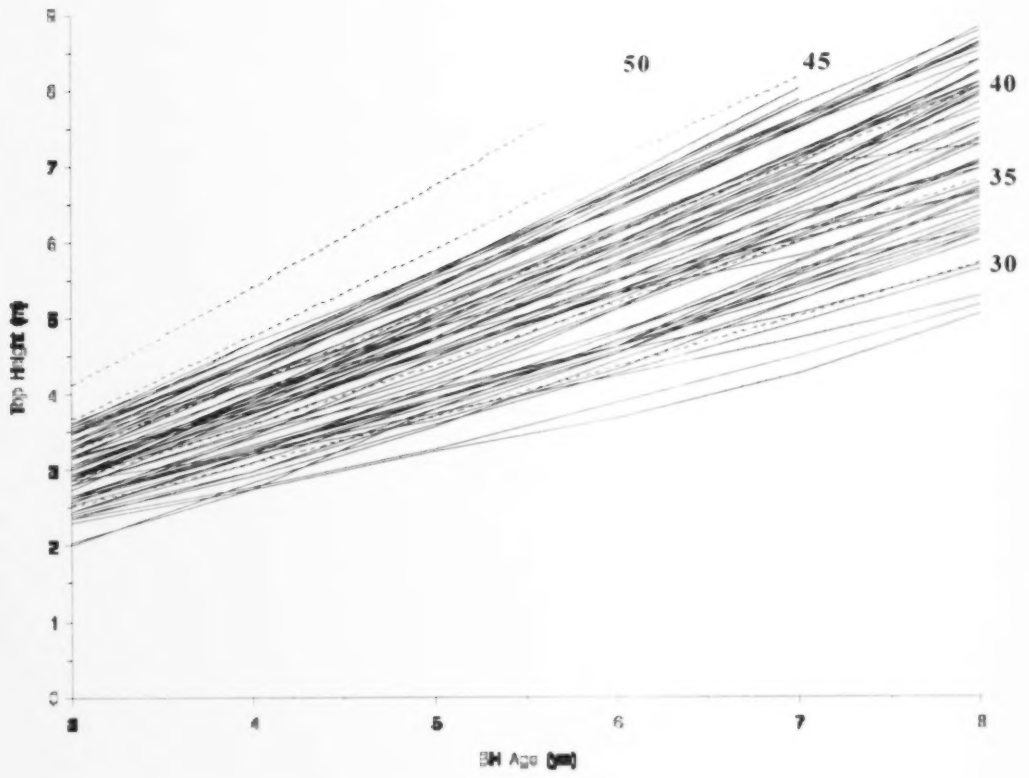

Figure 5. Height-age curves of current top height trees (solid lines) to age five and top height growth implied by GI model (dashed lines).